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SNO+

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Experiment Overview

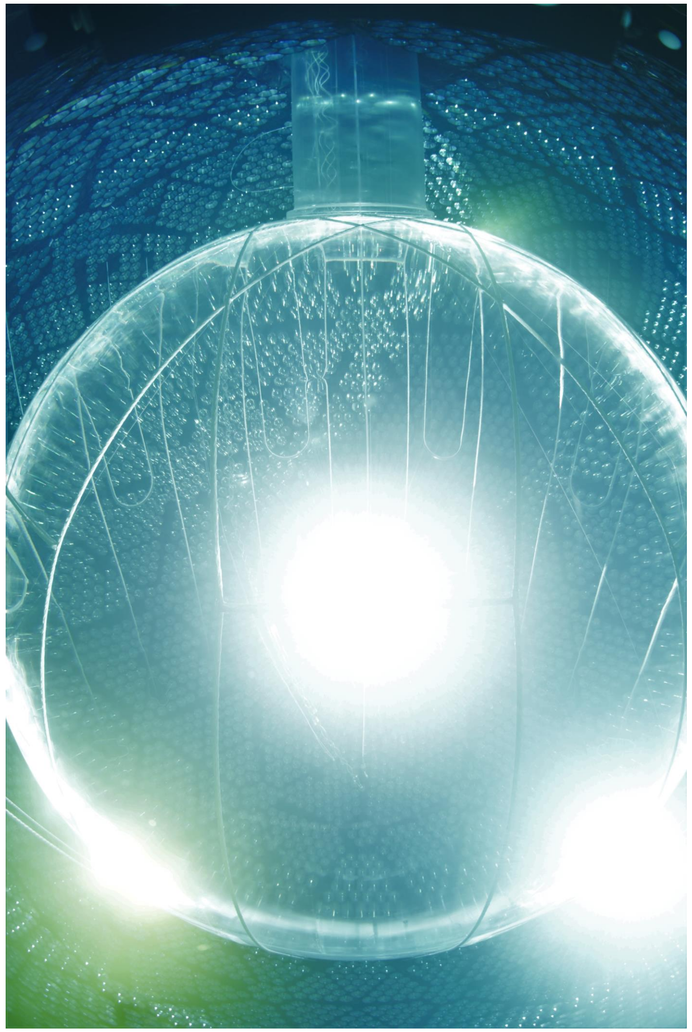
SNO+ is an <u>operating</u> neutrino detector with 780 tonnes of liquid scintillator

Water Phase: **completed**

- set world-leading limits on invisible nucleon decay
  PRD **99**, 032008 (2019); PRD **105** 112012 (2022)
- measured the ^{8}B solar neutrino flux with very low backgrounds
  PRD **99**, 012012 (2019)
- highest efficiency neutron detection in a water Cherenkov detector
  PRC **102**, 014002 (2020)
- first detection of reactor antineutrinos (IBD events) using pure water
  PRL **130**, 091801 (2023)

Pure Scintillator Phase: **since April 29, 2022**

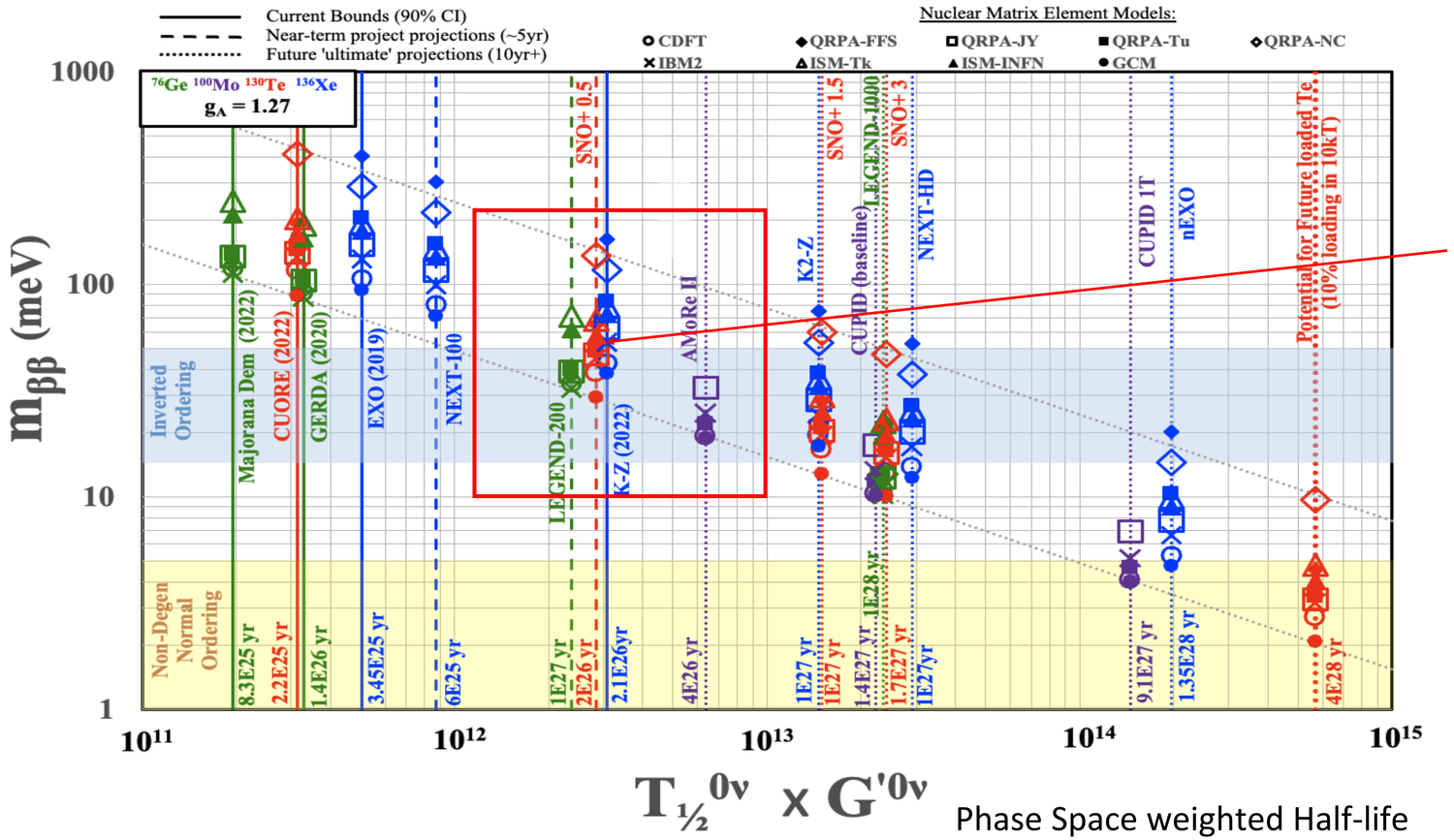
- detecting low energy ^{8}B solar neutrinos
- detecting geo and reactor antineutrinos to independently measure Δm^2_{12}
- supernova neutrino live
- event-by-event directionality in liquid scintillator



Experiment Overview

SNO+ is also a double beta decay experiment that will add more than 1,300 kg of ^{130}Te to the detector

- with sensitivity that reaches the Inverted Mass Ordering; addition of more Te at 1.5% loading now covers the IO parameter space



Phase Space weighted Half-life

34% natural abundance

Complementarity of isotope: Ge, Xe or Te can be best, depending on which NME model

Understanding of background is crucial

Scintillator phase serves as “target out” measurement

Experiment Overview

SNO+ Te DBD experiment is in the Canadian SAP LRP under “Flagship projects with broad physics outcomes”; is mentioned in the midterm report for APPEC (renewed status as CERN Recognized Experiment RE-35); is included in the US Nuclear Physics LRP White Paper for Neutrinoless Double Beta Decay, arXiv:2212.11099

6.3.1.4. Looking Beyond the Ton Scale

There is a vibrant and diverse experimental program worldwide in which Europe has achieved a recognised leadership and obtained an outstanding track record through its most prominent contributions to many experiments (CUORE/CUPID, GERDA/LEGEND, NEXT, NEMO-3/SuperNEMO, SNO+). Plans to enhance the sensitivity are being put forward in Europe, North America and Asia and aim to completely cover the inverted neutrino mass ordering, corresponding to an effective Majorana mass above 15 meV, while maintaining a discovery potential also for sufficiently large masses for the normal ordering.

Tellurium Plants – UG and Thin film distillation - surface

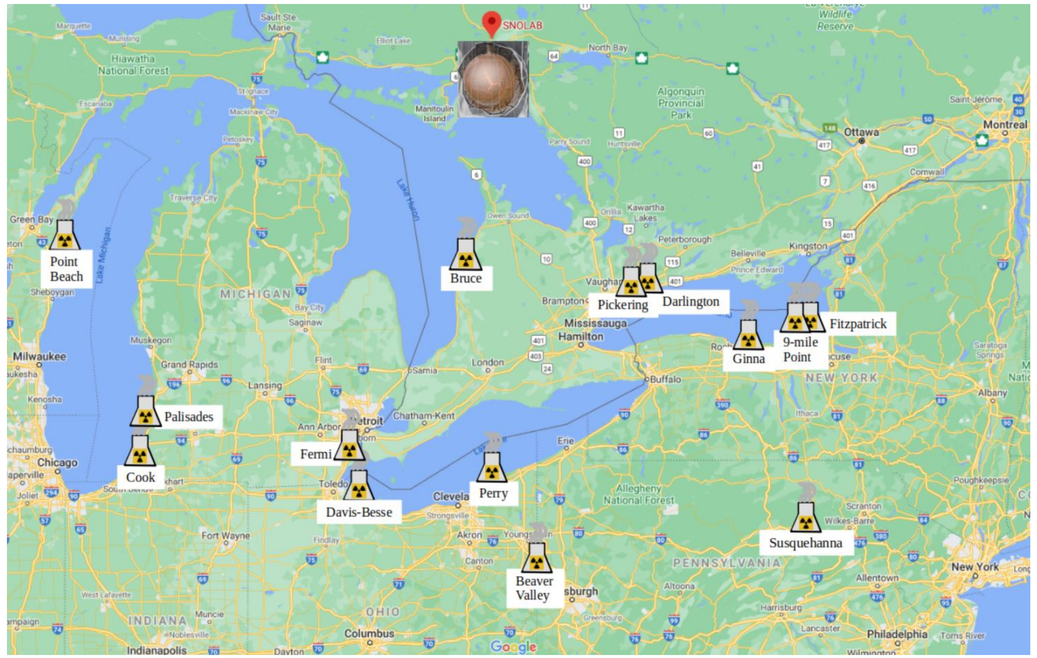
Thin film distillation unit
in surface clean labs

Start commissioning
March/April 2024

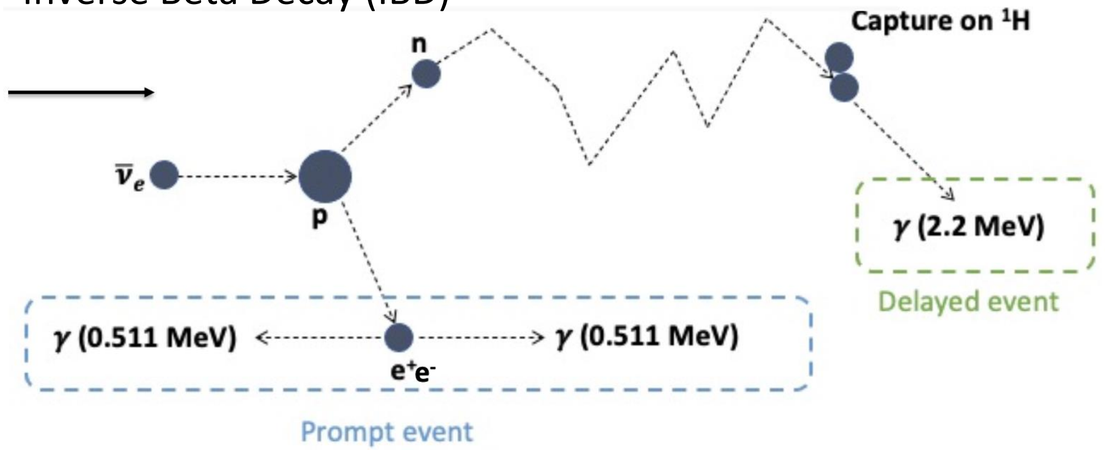
Tellurium systems have been installed, commissioned, being made ready for operations; full-scale test batches of TeA purification, underground begin in March-April 2024

Reactor Antineutrinos in SNO+

Scintillator Phase primary physics goal



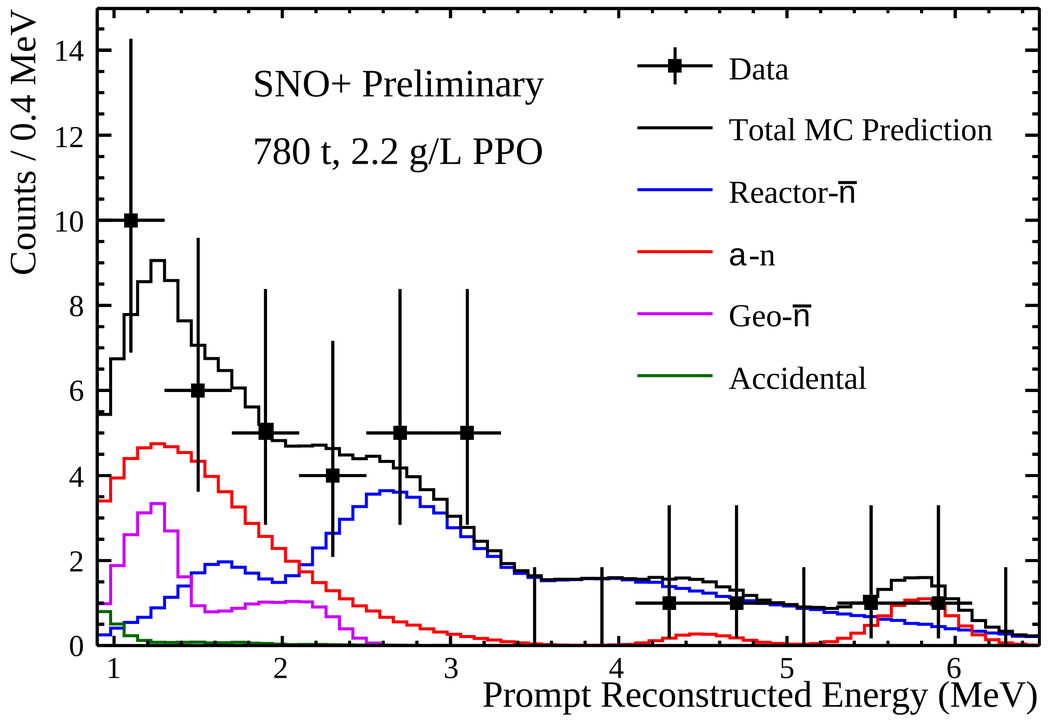
Inverse Beta Decay (IBD)



$$\bar{\nu}_e + p \rightarrow e^+ + n$$

New science developments

Scintillator Phase physics – preliminary antineutrino data shown at conferences



<u>IBD events from $\bar{\nu}_e$</u>

(α,n) events don't yet include classifier cut (being tuned for 2.2 g/L PPO proton-recoil timing)

Geo neutrinos are being detected; reactor neutrino Δm^2_{21} measurement underway

Collaboration Health

Provide any update and status of efforts to maintain an equitable, diverse, and inclusive culture within your collaborative activities

SNO+ has a Code of Conduct and Ombudspersons

Opportunity for young people

- Elected young members (2) to serve on the scientific board
- Working group leader – many Postdocs and also senior Ph.D. students
- Site work – anybody with expertise can pass it on and take appropriate leading roles

Formed EDI tasks force to develop SNO+ EDI plan **June 2023**

- Collaboration survey
- Document existing efforts
- Develop and document new and additional ideas
- Aim to complete during this calendar year

SNO+ Collaboration

7 countries

18 institutions

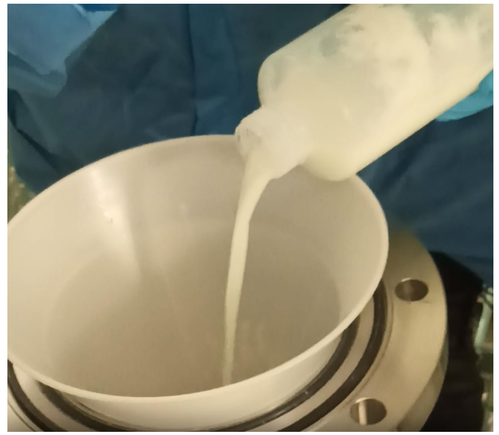
~110 authors (recent papers)

~60 people detector shifts

~30 people on site
(permanent of LTA)

Experiment Status

Scintillator Operations May – November 2023



Scintillator Operations

- Added ~2 mg/L bis-MSB secondary wavelength shifter to the detector to increase light yield by factor ~ ×1.6-1.7
- More uniform light collection versus radius
- Added BHT (stabilizer to scintillator cocktail)

Ongoing and upcoming

- Preparing plants for primary distillation
- Also preparing for tellurium phases – receiving BD

Bis-MSB addition (operationally)

Supported well by SNOLAB: operations, scientific support – THANK YOU

4 batches – between May and November

- Prepare the bisMSB Slurry:
  a. Take 2 x 4L glass bottles of LAB from Scint Plant to surface
  b. Add total of 0.5 kg of bisMSB to bottles in a Matt-Box@fumehood.snolab
  c. Bring slurry U/G
- Deploy 1 batch into V-501
  0.5kg of bisMSB in **500L** of LAB (1g/L)
  a) Add LAB to V-501 and warm it up
  b) Add bisMSB slurry and 3x P-P cycles
  c) Mix and recirculate till dissolved
  d) 2 Water Extractions
  e) Transfer V-501 → V-41
  f) Flush V-501 with the "pure" LAB
- Add Master Solution to the AV

Operations
QA (Uvis measurents, etc)
Preparation
Transport
Pouring and Mixing

Experiment Status

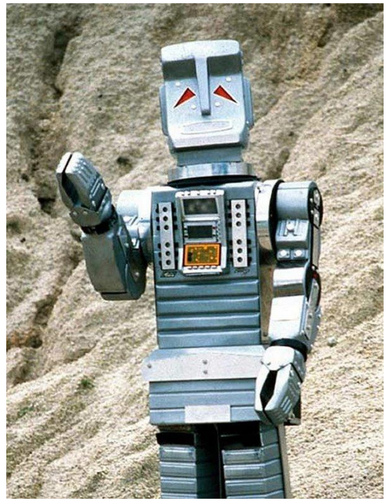
Tellurium Operations (Engineer, Ops, SNO+)

Tellurium Operations

- Preparing for upcoming telluric acid purification “test batch” — will be a major milestone involving purification of a full-scale batch (~200 kg) of telluric acid using nitric acid recrystallization
- In parallel – as time allows – look at outstanding commissioning/caveat items for diol plant
- Spill response team, QA, training
- Actively work on Transfer stations
- DDA thin film distillation apparatus in surface clean labs – after some more utility work, plan to start commissioning in March/April

Experiment Status

Data taking is ongoing including launch of Robo-shifter



Turning out to be this…

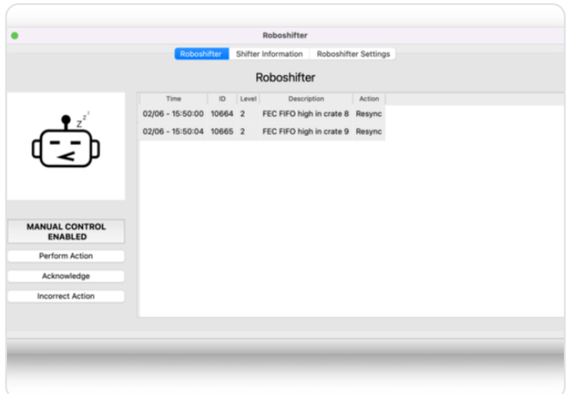
and not this… so that's pretty good!

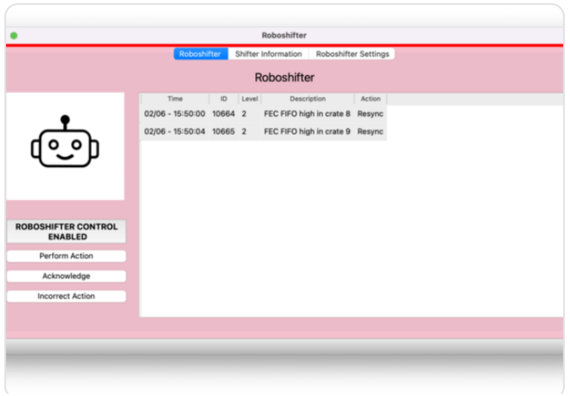
Since January 2024

- Roboshifter takes over Friday afternoon until Monday morning
- Eliminating 7 shifts (out of 21) each week
- In addition, it pre-fills all shift report – increased consistency

Testing phase, next steps

- April/May time scale – remove observation shifts
- August/September time scale – extend to weekday night shifts – elimination 4 more shifts (maybe earlier)
- Remove remaining 4 afternoon shifts with no people UG





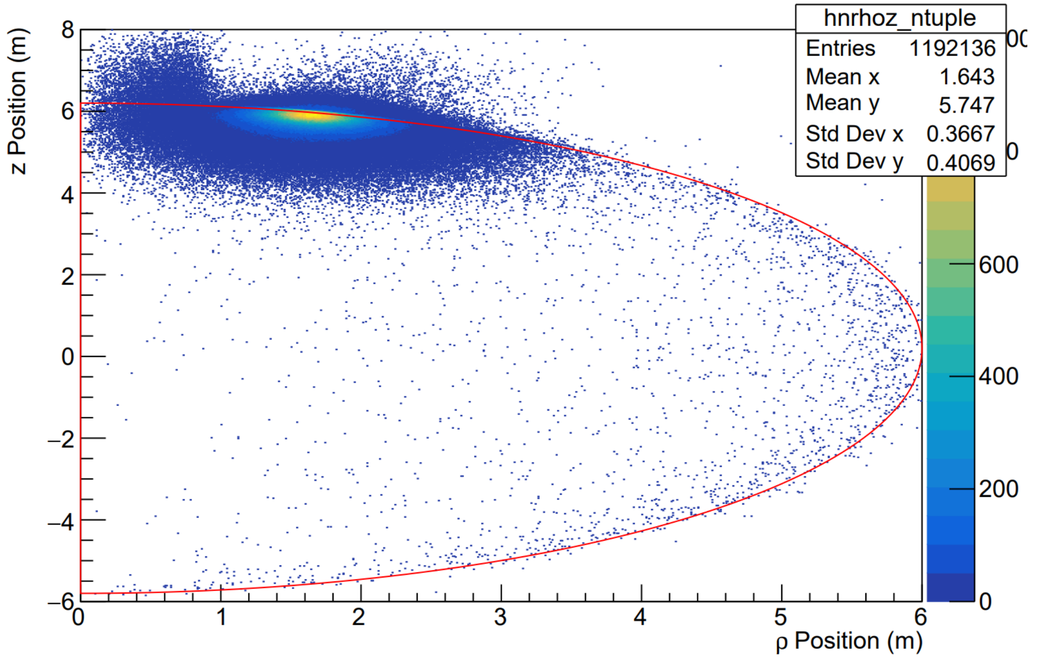
Experiment Status

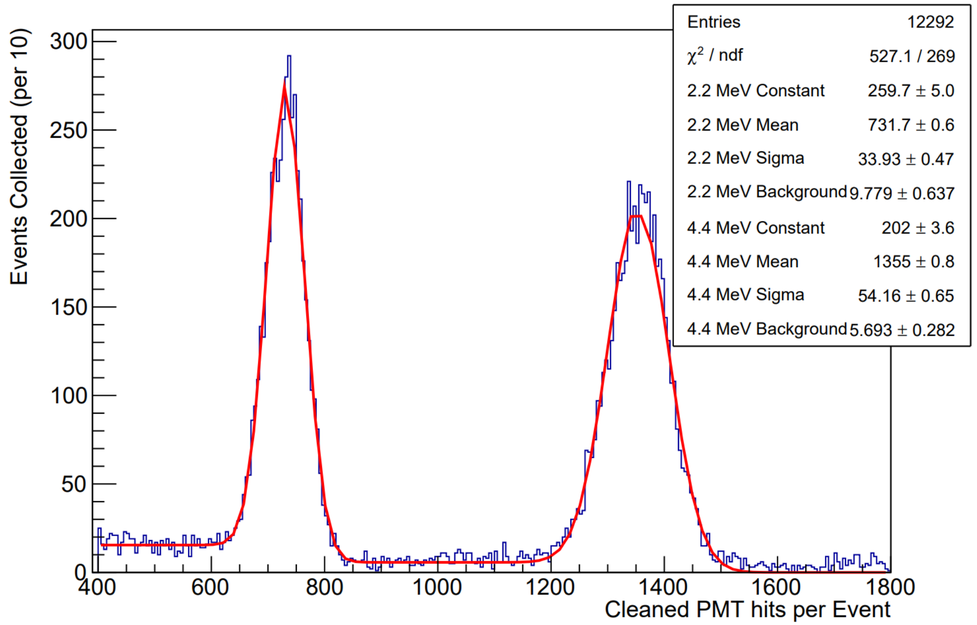
Calibrations - external

After Bis-MSB addition

- AmBe source - weekend
- Laserball scan – full week – 3 guidetubes

Utilized remote operations as well
5 wavelength per position
Analysis underway





Shift in 2.2 MeV and 4.4 MeV peak agrees with increase in light yield

Experiment Status

Assays (SNO+ and Scientific Support)

Reestablished HTiO water assay

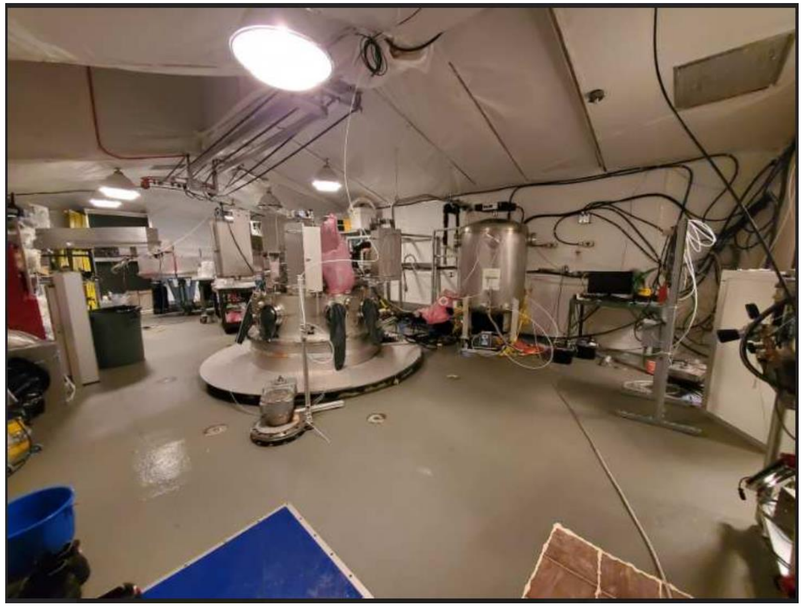
- Water clean
- Radon water assays look good

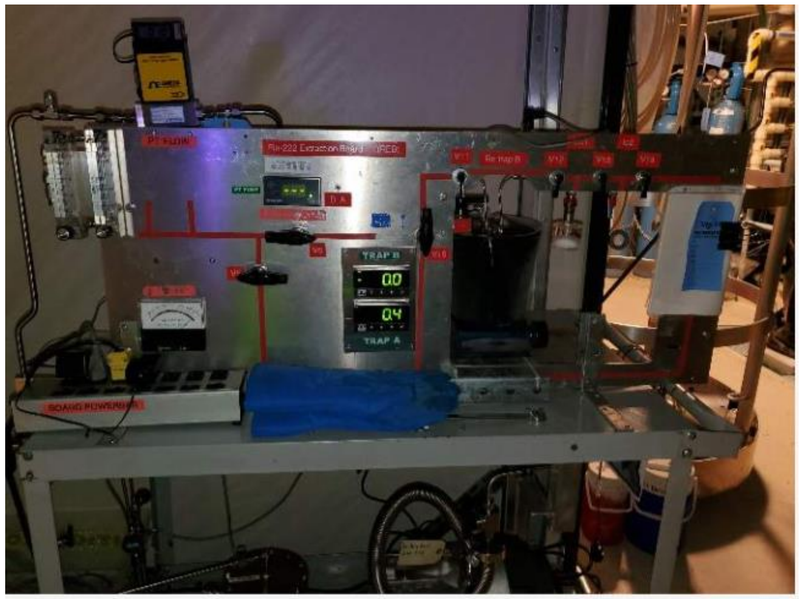
Gas assays, etc.

- Carefully monitor Radon
- Various gas volumes

Work on

- Scintillator radon board
- Scavenger assay board

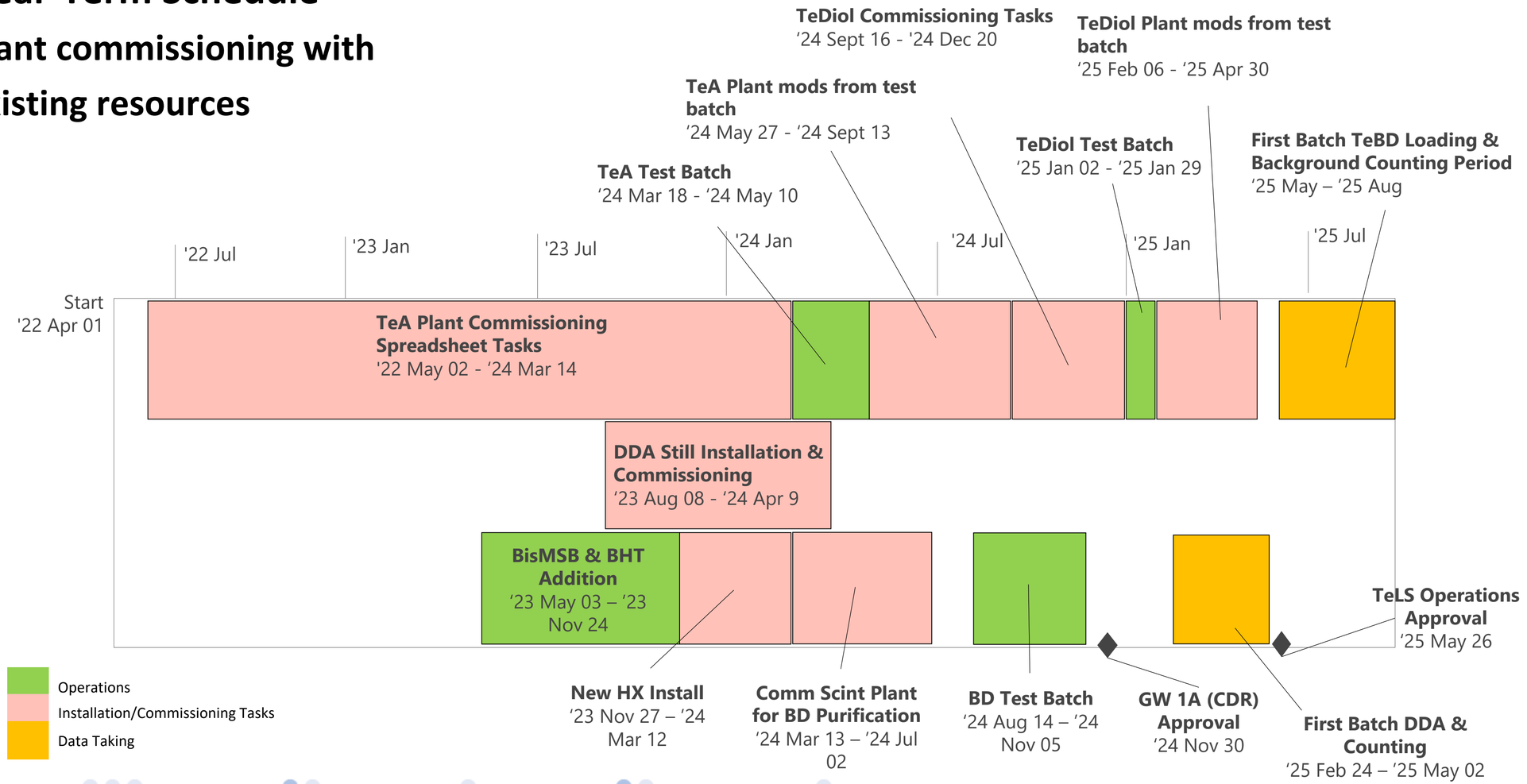




Schedule impacts & milestones

Near-Term Schedule

plant commissioning with existing resources



Challenges

Describe any short-term (6 months to 2 years) challenges you are experiencing or expect to experience in the project.

1) Liquid nitrogen supply at SNOLAB – the LN2 plant underground produces nitrogen with 3% Ar content. ^{39}Ar is not a *direct* background for any currently planned SNO+ physics measurement; but it's important to avoid putting in any backgrounds in the detector if it can be avoided (large rate, even at low energy, affects quantification of other backgrounds; introduces pile-up events; may affect searches for exotics). Stripping of SNO+ LS from the AV, with this nitrogen, is thus excluded. Status of underground LN2 dewars and shipments of LN2 to SNOLAB? Bottled nitrogen is also not suitable for stripping LS. Commissioning of steam stripping in the SNO+ scintillator plant offsets some but not all LN2 usage.
2) Te deployment operations (in 2025) would really benefit from more shift coverage UG – day and afternoon with overlap or from 24-hr shifts. If we can make that happen with SNOLAB and can find the required human resources, would make a big difference in the Te DBD schedule.

Conclusions

Moving forward with SNO+ Te double beta decay

- first test batch for TeA purification about to get underway
- TeDiol plant is also being prepared for an upcoming test campaign
- DDA operations are also being prepared
- CFI 2025 IF competition – NOI (internal) has been submitted – the ambition is to push the project's sensitivity further by procuring/deploying more tellurium
  - requires progress in the funding approval and project lifecycle
  - and key demonstrations of operational capabilities, backgrounds and TeLS optical properties following an initial deployment of Te in the detector (target early 2025)

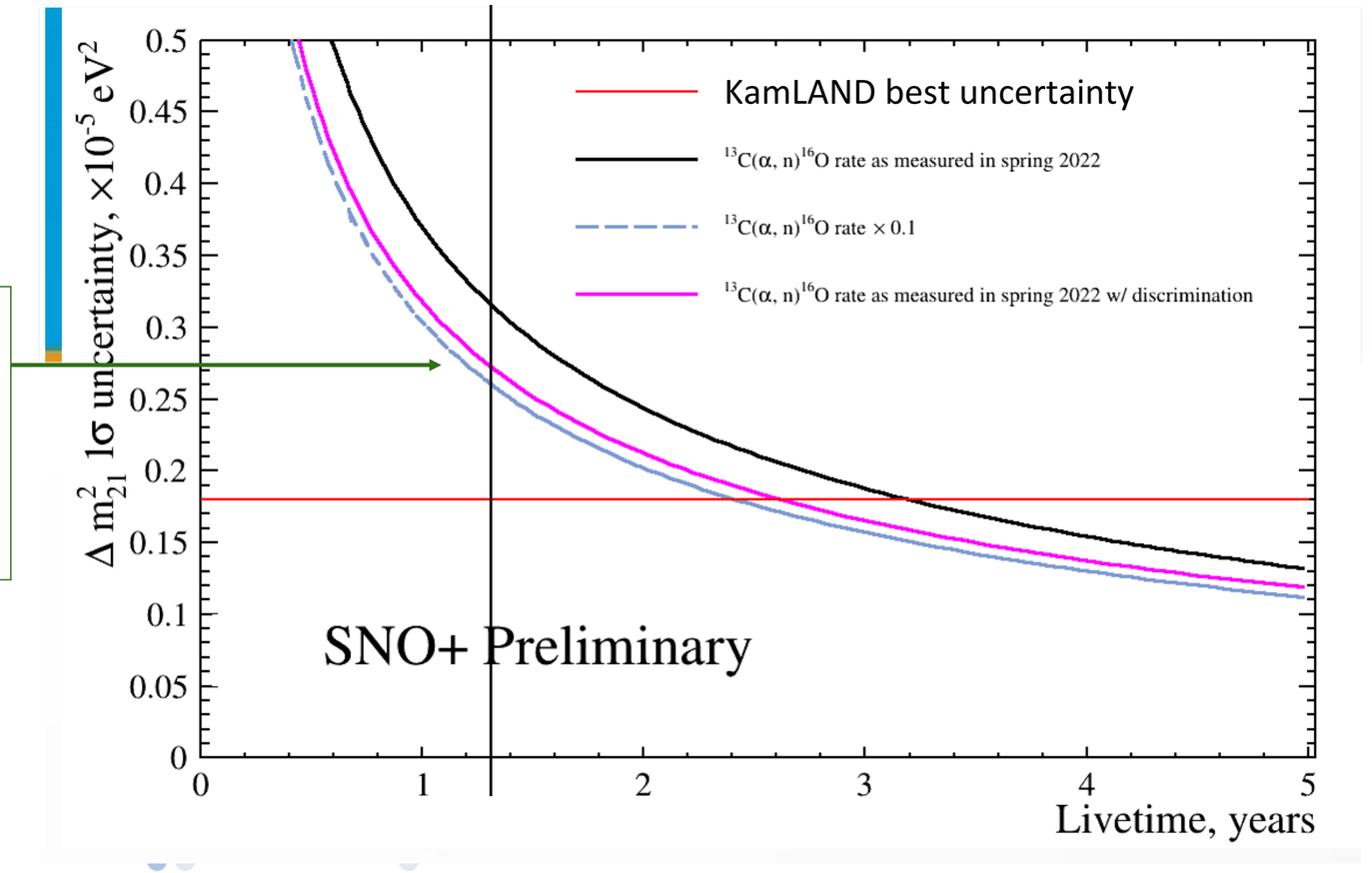
Scintillator phase data taking is going well and anti neutrino analysis is well underway

Backup Slides

Reactor Antineutrinos in SNO+ cont'd

Partial-LS Fill: measured flux and spectrum; oscillation analysis (paper being finalized)

Full LS (LAB + 2.2 g/L PPO since 2022): improved flux and spectrum precision; oscillation analysis will probe tension in Δm^2_{21}



FlareTek

Incident in the week before the anticipated start of TeA test batch – during water commissioning

Near miss – paused operations permit

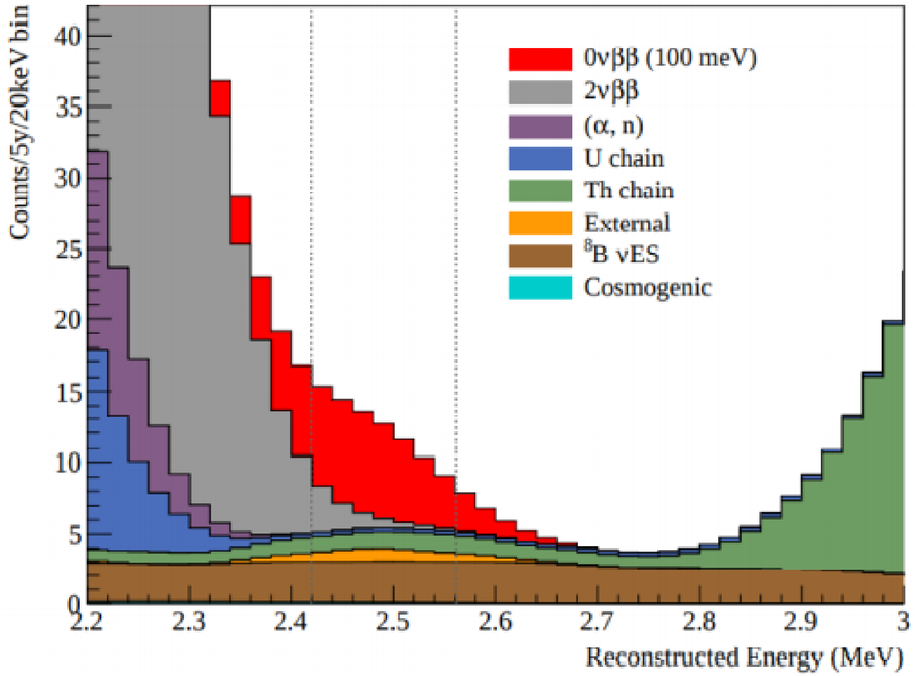
Actions: retorquing, new water commissioning, check torquing after heat cycle
minimize human presence while pumps running
maintenance schedule and risk matrix for fittings

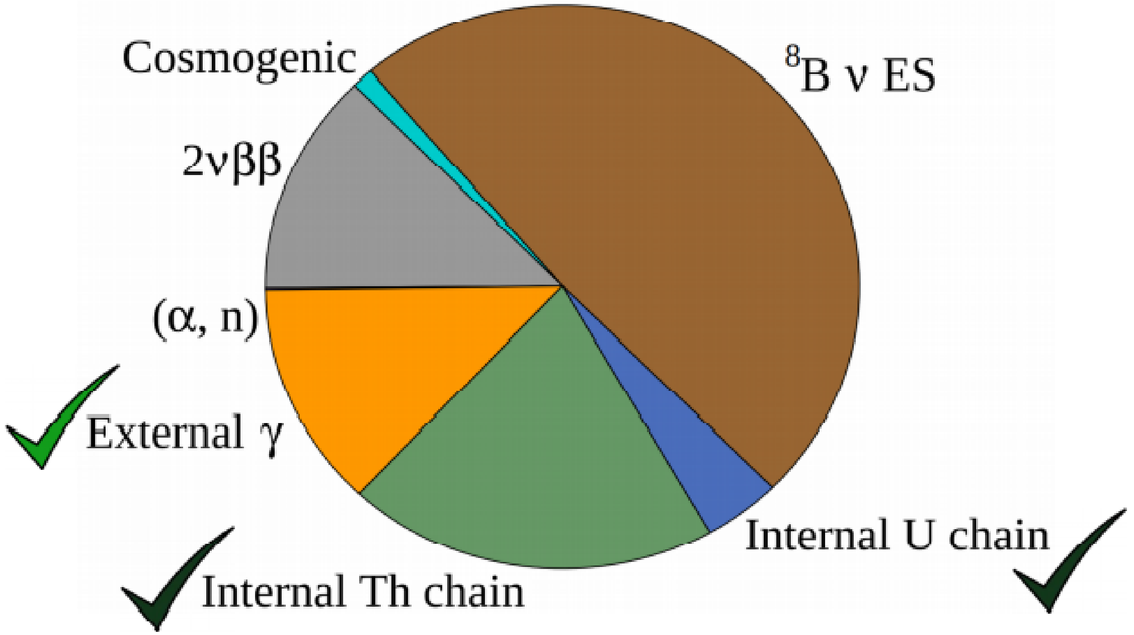
3D printed tools

Entegris purchased tool (1/2”)

Neutrinoless double beta decay

Target: Liquid scintillator doped with 4 t natural tellurium





9.47 background counts/yr → $T_{1/2}$>2.1 x 10^{26} yrs

after 5 yrs with 0.5 % Te (Phase I)

Measured and on target

Measured and on target for LAB

Transition – higher loading (1.5% or 2.0% maybe more)